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Road vehicles — Apparatus for measurement of the opacity of exhaust gas from diesel engines

Véhicules routiers — Dispositif pour le mesurage de l'opacité des gaz d'échappement des moteurs diesel

Technical Report 4011 was drawn up by Technical Committee ISO/TC 22, *Road vehicles*, and approved by the majority of its members. The reasons which led to the publication of this document in the form of a Technical Report are the following :

This Technical Report was prepared on the basis of present knowledge concerning the design and use of opacimeters intended in particular for measuring the opacity of exhaust gas from diesel engines running in free acceleration; this type of measurement is in fact a necessity when the legislation requires a control of the opacity of the smoke emitted by the vehicle in service; it is then essential that a device and a measurement method be available which allow reproducible and repeatable measurements to be made.

However, during the study, some difficulties arose in establishing with precision certain performance characteristics in relation to the response time of the device when the opacimeter is used in transient conditions.

Consequently, the type of device described below was not considered suitable for definition in an International Standard.

A study is in progress to fix the whole of the characteristics of the opacimeter.

CONTENTS

	Page
1 Scope	2
2 Field of application	2
3 Reference	2
4 Principle of opacimeters	2
5 Basic specifications for opacimeters	2
6 Construction specifications	3
7 Information and methods of measurement to be provided by the manufacturer	5
8 Verification of opacimeter types	6
Annex : Installation and use of opacimeters	16

1 SCOPE

This Technical Report establishes the specifications for devices for measuring the opacity of exhaust gas from diesel engines for road vehicles, and for their installation. These instruments are generally known as "opacimeters". The annex deals with the installation and use of opacimeters.

2 FIELD OF APPLICATION

This Technical Report concerns opacimeters for use in steady state and free acceleration conditions for diesel engines of road vehicles. It does not cover :

- free-piston engines;
- stationary engines;
- marine engines;
- railway engines;
- aircraft engines;
- engines for agricultural tractors and special vehicles for use in civil engineering.

3 REFERENCE

ISO 3173, *Road vehicles — Apparatus for measurement of the opacity of exhaust gas from diesel engines operating under steady state conditions*.

4 PRINCIPLE OF OPACIMETERS

The principle of measurement consists in passing a beam of light through a certain length of the medium to be measured. The proportion of the incident light reaching a receiver (for example, a photoelectric cell) is used to assess the opacity of this medium.

The opacimeter may be constructed to take the full flow of exhaust gas delivered by the engine (full flow opacimeter) or only a sample (sampling opacimeter).

Opacimeters are used under two types of test conditions :

- **Steady state conditions** : The engine is run at constant speed and under constant load; the opacimeter operates under steady state conditions (SS).
- **Transient conditions** : The engine is run under transient conditions of speed and/or load; the opacimeter operates under transient conditions (TC).

Opacimeters may also exist which are suitable for use only under steady state conditions. These are the subject of ISO 3173. Apparatus conforming to this Technical Report conforms *ipso facto* to ISO 3173.

5 BASIC SPECIFICATIONS FOR OPACIMETERS

5.1 The gas to be measured is passed through a chamber the internal surface of which is non-reflecting, or through an equivalent optical environment.

5.2 The effective path length of the light rays through the gas to be measured is determined taking into account the possible influence of devices for protecting the light source and the photoelectric cell. This effective length shall be indicated on the apparatus.

5.3 The measuring device shall have the following characteristics :

5.3.1 The indicator of the opacimeter shall have a measuring scale graduated in units of light absorption coefficient from 0 to 5 m^{-1} at least.

5.3.2 The indicator shall allow a light absorption coefficient to be read between 0 and 3 m^{-1} with a precision of $0,05 \text{ m}^{-1}$ at least.

5.3.3 The measuring device (for transient conditions only) shall allow the maximum opacity to be stored for at least 5 s and allow instantaneous cancellation of the value stored. This value shall not decay by more than 1 % during this time. The peak hold device shall be able to be switched out of circuit.

5.4 The total absolute uncertainty shall be less than :

- 0,2 m^{-1} for a light absorption coefficient between 0 and 3 m^{-1} ;
- 0,5 m^{-1} for a light absorption coefficient between 3 and 5 m^{-1} .

6 CONSTRUCTION SPECIFICATIONS

6.1 General

The design shall be such that in steady state conditions the smoke chamber is filled with a uniform smoke and the pipes and fittings and devices for bringing the gases into the measuring chamber do not include any sharp bends where soot could accumulate.

The impingement on the receiver of stray light due to internal reflection or the effects of diffusion shall be reduced to a minimum (for example by coating the internal surfaces in matt black and by an appropriate general layout).

6.2 Measuring zone of the smoke chamber

6.2.1 The measuring zone is that part of the smoke chamber in which the measurement is made. It is bounded :

- at its two extremities by the devices for protecting the light source and the receiver, defining the effective length of the apparatus;
- parallel to the flow of gas by the lower and upper surfaces of the smoke chamber;
- if applicable, perpendicular to the flow of gas by two imaginary planes, one of them representing the front of the incoming gas, the other the front of the outgoing gas flow, which form tangents to the beam of light reaching the receiver.

6.2.2 The speed of the gases through the measuring zone shall not differ by more than 50 % from the average speed over 90 % of the length of the measuring zone.

6.3 Light source

The light source shall have a colour temperature between 2 800 and 3 250 K within limits specified by the manufacturer for the supply voltage of the apparatus.

6.4 Receiver

6.4.1 The receiver shall be made up of a photoelectric cell with a spectral response curve similar to the photopic curve of the human eye (maximum response in the band of 550 to 570 nm, less than 4 % of this maximum response being below 430 nm and above 680 nm).

6.4.2 The apparatus shall be so designed that :

- the rays of the light beam are parallel within 3° to the optical axis;
- the receiver does not take into consideration the direct or reflected light rays with an angle of incidence greater than 3° to the axis of the optical device.

Any system giving equivalent results will be acceptable.

6.4.3 The design of the electric measuring circuit, including the indicator, shall be such that the display value of the indicator is a monotonic function of the light absorption coefficient in the range of normal operating temperatures of the apparatus.

6.5 Measuring scale

The light absorption coefficient k (m^{-1}) is calculated according to Beer's law by the formula

$$k = \frac{\log_e(\phi_0/\phi)}{L}$$

where

L is the effective length of the light path through the gas to be measured;

ϕ_0 is the light flux received by the receiver when the measuring zone is filled with clean air;

ϕ is the light flux received by the receiver when the measuring zone is filled with smoke.

6.6 Adjustment and checking of the measuring apparatus

6.6.1 The electrical circuit of the photoelectric cell and of the indicator shall be adjustable so that the indicator can be reset at zero when the light flux passes through the measuring zone filled with clean air or through a chamber with identical characteristics.

6.6.2 Two neutral optical filters (or equivalent devices) shall be provided with each opacimeter so that the accuracy and linearity of measurement of the measuring device may be checked. These filters shall have equivalent absorption coefficients as defined in 6.5, between 1,5 and 2,0 m^{-1} and between 4,5 and 5,0 m^{-1} respectively. Their values shall be known to the nearest 0,025 m^{-1} . Provision shall be made for them to be placed on the path of the light rays passing through the measuring chamber filled with clean air or through a chamber with identical characteristics. Measurement apparatus with automatic temperature compensation must simulate 100 °C during the checking tests.

6.7 Response of the opacimeter

6.7.1 Physical response time of the opacimeter

This is the time t necessary for a given discharge of gas, Q , to fill the volume V of the measuring zone defined in 6.2.1.

This time may be estimated with sufficient precision by means of the formula

$$t = V/Q$$

For transient conditions, the opacimeter will be satisfactory if $t \leq 0,075 \text{ s}^*$.

For opacimeters used only for steady state conditions, the manufacturer shall state the response time.

6.7.2 Electrical response time

This is the time elapsing between the moment when the light source is sealed off in less than 0,01 s, and the moment when the device recording the measuring signal reaches 90 % of the level of its final signal. For transient conditions, this electrical response time shall be equal to $0,1 \pm 0,01 \text{ s}^*$.

For opacimeters used only for steady state conditions, the manufacturer shall state the response time.

The electrical circuit shall in addition include a filtration of the measuring signal. This is obtained by means of a low-pass filter with breaking frequency of 10 Hz, possessing a frequency response curve between + 0,5 and - 1 dB up to 16,5 Hz and with a slope equal to $12 \pm 6 \text{ dB/octave}$ for frequencies greater than 16,5 Hz.

6.8 Pressure of the gas to be analysed

6.8.1 The static pressure of the exhaust gas in the smoke box shall not differ from that of the ambient air by more than 7,5 mbar.

6.8.2 The opacimeter shall be fitted with devices suitable for allowing the fitting of apparatus for measuring the static pressure in the smoke box. The readings shall be taken with an uncertainty of less than 0,1 mbar.

* Provisional values.

6.9 Temperature of the gas to be analysed

6.9.1 The opacimeter shall be fitted with the devices necessary for estimating the average temperature of the gas in the measuring chamber; the manufacturer shall specify the limits of operation. The uncertainty of measurement shall be taken into account when calculating the total measuring uncertainty of the apparatus.

6.9.2 At all points of the measuring chamber, the temperature of the test gas at the instant of measurement of opacity shall be not less than 60 °C and the average temperature in the chamber shall be not greater than 400 °C. The range of normal use shall be indicated by the manufacturer.

6.9.3 The opacimeter reading must be corrected to 100 °C by means of the formula

$$k_{\text{corrected}} = k_{\text{observed}} \times \left(\frac{t + 273}{373} \right)$$

where t is the temperature, in degrees Celsius, of the test gas.

6.9.4 The thermal time-constant of the device for measuring temperature shall be

- indicated by the manufacturer;
- commensurate with the recommended operating time of the instrument for steady state use;
- less than 5 s for opacimeters used in transient conditions.

The thermal time-constant is the time necessary for the sensor to reach 63 % of the difference in temperature between the initial state and the final state in still air.

6.10 Details of design

Any devices which may be situated upstream of the measuring zone shall not affect the opacity properties of the gas entering the chamber by more than 0,05 m⁻¹ for a gas with an opacity of 1,7 m⁻¹.

6.11 Total measurement uncertainty

The total measurement uncertainty Δk is given by the formula

$$\Delta k = \sqrt{\sum_i (\Delta k_i)^2}$$

where the Δk_i are principally the following uncertainties :

- a) error due to the geometry of the apparatus (effective length);
- b) error due to the optical and electrical devices (including soiling of lamp and photoelectric cell) :
 - zero error and sensitivity error of the measuring device;
 - error due to the indicator;
 - error due to measurement and correction for average temperature.

Δk shall not exceed 0,2 m⁻¹.

Errors due to parameters other than those mentioned in this specification shall also be taken into account if it is considered that their influence is likely to be significant.

7 INFORMATION AND METHODS OF MEASUREMENT TO BE PROVIDED BY THE MANUFACTURER

7.1 Handbook for maintenance and use to be provided with each apparatus

This document shall deal with the following points :

7.1.1 Technical description of the opacimeter, including a diagram of the optical and electrical devices and dimensional sketches of the measuring chamber and the adjacent areas, with tolerances.

7.1.2 Information on the maintenance of the opacimeter, and in particular, the cleaning intervals and all the special operating precautions peculiar to the given model, including whether the opacimeter is designed to operate continuously or intermittently and, in the latter case, the time necessary for passing smoke through the opacimeter before a correct measurement can be taken (operating time).

List of the periodic checks which the apparatus requires.

7.1.3 Effective length of the smoke column used to calculate the light absorption coefficient.

7.1.4 Operating limits of the light source, i.e. either :

- a) limits of voltage at the terminals of the light source and instructions on its life, or
- b) limits of reading with a gauging colour filter provided with each opacimeter.

7.1.5 Total precision of the apparatus as defined in 6.11 and the range of corresponding ambient and exhaust gas temperatures.

7.1.6 Minimum flow of gas into the smoke chamber corresponding to the time of maximum physical response imposed in 6.7.1 and the maximum flow of gas into the smoke chamber corresponding to the maximum gas pressures allowed by the manufacturer.

7.1.7 Instructions relating to limits on fittings which may be attached to the opacimeter exit, giving equivalent orifices.

7.2 Data to be provided for the conformity check of the type of opacimeter

7.2.1 Temperature of the surface of the photoelectric cell above which its response features change significantly.

7.2.2 Relationship between the temperature indicated by the measuring device and the average temperature in the smoke chamber.

7.2.3 Nominal supply voltage limits within which the opacimeter will operate satisfactorily (separate limits must be given for each supply point where more than one exists).

7.2.4 Response time of the electric measuring circuit necessary for reaching 90 % of the level of continuous signal following sealing off of the light source in less than 0,01 s.

7.2.5 Relationship between the static pressure and the gas flow in the smoke chamber.

7.3 Methods of measurement used in the conformity check of the type of opacimeter

The opacimeter must allow the attachment of instruments necessary for measuring the following parameters :

- a) static pressure of the exhaust gas in the smoke box;
- b) temperature at the point specified by the manufacturer for measuring the gas temperature;
- c) voltage of the lamp (unless a particular method using a colour filter is laid down for checking the colour temperature);
- d) output current of the photoelectric cell.

8 VERIFICATION OF OPACIMETER TYPES

8.1 Scope

This clause gives details of the procedures to be adopted to check that an opacimeter of a given type corresponds to the requirements of clauses 5, 6 and 7. It deals with opacimeters in general. When possible, each heading includes a reference to the corresponding sub-clause of clauses 5, 6 and 7 to which the test refers. The checks cannot, however, cover all the possible models of opacimeter. It will rest therefore with the organization approving a given type of opacimeter to check the possible influence of the devices which belong to each apparatus.